PREDICTION OF GRINDING MACHINING PARAMETERS OF DUCTILE CAST IRON USING WATER BASED ZINC OXIDE NANOPARTICLE

MOHD SABARUDIN BIN HJ SULONG

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UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

This project presents the prediction the grinding machining parameters for ductile cast iron using water based Zinc Oxide (ZnO) nanoparticles as a coolant. Studies were made to investigate the experimental performance of ductile cast iron during grinding process based on design of experiment. Response surface modeling (RSM) is practical, economic and relatively easy for use. The experimental data was utilized to develop the mathematical model for first- and second order model by regression method. Contour plot is a helpful visualization of the surface when the factors are no more than three and in order to locate the optimum value. The quality of product was determined by output criteria that are minimum temperature rise, minimum surface roughness and maximum material removal rate. Based on prediction data, the second-order gives the good performance of the grinding machine with the significant p-value of analysis of variance that is below than 0.05 and support with R-square value nearly 0.99. From the model profiler and contour plot, the optimum parameter for grinding model is 20m/min table speed and 42.43µm depth of cut could for single pass grinding. For multiple pass grinding it optimized at the table of speed equal to 35.11m/min and 29.78µm depth of cut could for has best quality of product. As the conclusion, objectives were achieved where the grinding parameters were optimized, grinding performance was investigated and mathematical model for abrasive machining parameter was developed. The model was fit adequate and acceptable for sustainable grinding using 0.15% volume concentration of zinc oxide nanocoolant.

ABSTRAK

Projek ini membentangkan ramalan parameter pemesinan perlelasan bagi besi tuang mulur menggunakan Zink Oksida (ZnO) nanopartikel berasaskan air sebagai penyejuk. Kajian telah dibuat untuk menyiasat prestasi eksperimen besi tuang mulur semasa proses pelelasan berdasarkan reka bentuk eksperimen. Tindak balas pemodelan permukaan (RSM) adalah praktikal, ekonomi dan agak mudah untuk digunakan. Data eksperimen telah digunakan untuk membangunkan model matematik bagi model peringkat pertama dan kedua melalui kaedah regresi. Plot kontur adalah visualisasi membantu permukaan apabila faktor adalah tidak lebih daripada tiga dan untuk mencari nilai optimum. Kualiti produk telah ditentukan oleh kriteria output yang kenaikan suhu minimum, kekasaran permukaan minimum dan kadar penyingkiran bahan maksimum. Berdasarkan kepada data ramalan, peringkat kedua memberikan prestasi yang baik mesin pengisaran dengan ketara p-nilai analisis varians yang di bawah daripada 0.05 dan sokongan dengan nilai R-persegi hampir 0,99. Dari Profiler model dan plot kontur, parameter optimum bagi model pengisaran adalah 20m/min kelajuan meja dan kedalaman 42.43µm potongan boleh untuk pengisaran tunggal. Untuk pengisaran ulang-alik dioptimumkan di meja kelajuan yang sama dengan kedalaman 35.11m/min dan 29.78µm potongan mampu bagi mempunyai kualiti yang terbaik produk. Sebagai kesimpulan, objektif telah dicapai di mana parameter pengisaran dioptimumkan, prestasi pengisaran telah disiasat dan model matematik untuk parameter pemesinan melelas telah dibangunkan. Model itu patut mencukupi dan diterima untuk pengisaran mampan menggunakan jumlah kepekatan 0.15% daripada penyejuk nano zink oksida.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Mm	Millimetre
cm	centimetre
L	length
Ra	Roughness average
$W \cdot m^{-1} \cdot K^{-1}$	Watt per meter per Kelvin
m/min	Metre per minute
µm	micrometre
cm^3/min	Centimetre cubic per minute
L	Litter
CS	Cutting speed
A	Area
%	Percent
$\emptyset_1$	Initial volume concentration
Ω	Weight percent of nanofluid
ρ_w	Density of water
ρ_{ZnO}	Density of zinc oxide particle
Δv	Volume of distilled water required
v_1	Initial volume of nanofluid before dilute

LIST OF ABBREVIATIONS

MRR	Material removal rate
ZnO	Zinc oxide
CuO	Cooper oxide
TiO	Titanium oxide
CLA	Center line average
Cu	Cooper
Fe	Ferrum
Au	Gold
Ag	Silver
SiC	Silicon carbide
Al2O3	Aluminium oxide
SEM	Scanning electron microscope
TR	Temperature rising
SR	Surface roughness
MQL	Minimum quantity liquid
CuSO4•5H2O	Copper sulfate pentahydrate
NaH2PO2• H2O	Sodium hypophosphite

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Grinding widely used as the finishing machine for components that require smooth surface roughness and precision dimension and the processes are mainly the technique employed widely as a finishing and difficult-to machine such as hardness and brittleness materials finishing. However, in the grinding process, high grinding zone temperature may lead to thermal damage to the work surface, induces micro-cracks and tensile residual stresses in the ground surfaces, which deteriorate since surface quality and integrality of the ground surface (Hryniewicz et al., 2001). On the other hand, wear on grinding wheel is also a major problem since grinding is an abrasive process where the two surfaces are sliding each other. To decrease the wear rate on grinding wheel is a great challenge. Thermal damage of the workpiece can reduce by the application of a flood delivery grinding fluid that removes the heat created by the workpiece interaction and lubricates the two surfaces in order to decrease the amount of friction and tool wear can be reduced (Brinksmeier and Minke, 1993)

Nanofluid is new class fluid engineered by dispersion of solid particle with small diameter measured in less than 100 nanometers in based fluid to enhance thermal properties and tribological properties. Nanofluids have the potential to be the next generation of coolants due to their significantly higher thermal conductivities. Appropriate selection of a base fluid is very critical in the application of nanoparticle-based lubricants in grinding and proper selection of the cutting parameters for machining is obtain performances (Hryniewicz et al., 2001). When there are suspended crystalline solid particle with nanometre dimension in the based fluid such as water, ethylene glycol, lubrication oils, etc. to form a stable homogenous suspension and it increase the thermal conductivity relative to the based fluid so the suspension called Nanofluid. The thermal conductivity and the convection heat transfer coefficient of the fluid can be largely enhanced by the suspended nanoparticles (Malkin and Guo, 2007). Trybological research also found that lubricating oil with nanoparticle would exhibit the friction reduction properties. These features make nanofluid and nanoparticle useful and need to be improve beside apply in industries especially in heating and cooling, machining process, lubrication, transportation energy and electronics.

Response surface methodology (RSM) is combination of statistical technique where useful for analyzing and modelling problem in interested response that influence by several variables (Montgomery, 2005). The several experiment needs to conduct and the result from the experiment will collected before the data was analyzed. The goal of this research is an investigate maximum material removal rate and optimize machining parameter so that the surface roughness will minimize and material removal rate (MRR) to be maximized when using water based Zinc Oxide nanocoolant. Statistical method is used to prepare the design of experiments and find optimum parameters.

1.2 MOTIVATION OF THE PROJECT

Grinding is widely used in industries usually used as the finishing machining for components that require smooth surface roughness and precision dimension. It can produce very fine surfaces and very accurate dimensions and available in either hard or brittle materials. However, almost all energy in grinding process converts to heat and make the temperature rising up. The heat becomes concentrated in grinding zone so that the workpiece was heated at high temperature and possibility the workpiece surface damage due to the thermal effect (Komanduri and Reed, 2008). However, there is a little work on nanofluid based coolant in grinding processes since this is a new thing and lack of consistency result regarding thermal properties (Murshed et al., 2008; Wong and Kurma, 2008). There are a lot of previous research had done based on grinding process such as minimum quantity lubricant in the grinding process, surface modelling for conventional grinding, flow of the coolant etc. The goal of this research is coming with prediction of material removal rate and optimum grinding characteristic of ductile cast iron using zinc oxide nano-particle.

1.3 OBJECTIVES OF PROJECT

The objectives of the project are as follows:

i. To investigate the experimental performance of ductile cast iron during the grinding process based on design of experiment.
ii. To develop mathematical models for abrasive machining parameter using response surface method.

1.4 SCOPE OF THE STUDY

i. Design of experiment
ii. Prepare ZnO nanocoolant.
iii. Perform experiment on Grinding machine utilizing abrasive grinding wheel using water based ZnO nanocoolant on ductile cast Iron grinding process
iv. Perform the statistical analysis using central composite methods and
v. Perform surface roughness and G-ratio analysis

1.5 ORGANIZATION OF PROJECT

Chapter 2 presents the literature review on nanofluids, grinding process and response surface modelling. The methods of nanofluids synthesis were introduced, and their characteristic was discussed and for the grinding process, machining parameter involved such as wheel speed, table speed, depth of cut and other was discussed. Chapter 3 also presents the details information related to methodology of the experiment. Chapter 4 focuses on result and analysis, from the various combinations of input parameters such as wheel speed, table speed, depth of cut and G-ratio, material removal rate, surface roughness, and temperature. The results are analyzed to have an optimum input machining parameter. and the conclusions or recommendations for future work presented in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Grinding is an abrasive process where the workpiece is a force against the grinding wheel. Because of abrasive wear, the process generates chips that remove from the workpiece surface. However, the forces that generate during the process are converted into heat that causing the high temperature, particularly at the wheel and the workpiece interfaces. Grinding is a large and diverse area of manufacturing and tool making. It can produce fine surfaces and very accurate dimensions and available in either hard or brittle materials. High temperatures can cause thermal damage to the workpiece, which affects the workpiece quality and limits the process productivity (Malkin and Guo, 2007). Grinding wheel wear is a major problem that needs to overcome. To control heat and wheel wear or to improve the grinding performance, a heavy amount of grinding fluids (coolant) is used. The conventional cutting fluids used in grinding are considered a problem, as these substances can cause a large amount of mist, which is environmentally challenging and is expensive (Silva et al., 2005). This research interested nanofluid as the coolant in grinding machining process.

Nanofluid is a new class of fluids engineered by dispersing nanometer-size solid particles in base fluids such as water, ethylene glycol, engine oil, cutting fluids. The thermal conductivity and the coefficient of convection heat transfer of the fluid can largely enhanced by the suspended nanoparticles recently. Tribology research shows that lubricating oils with nanoparticle additives. These features make the nanofluid very attractive in some cooling and/or lubricating application in many industries, including manufacturing, transportation, energy, and electronics. Previous study stated that grinding conditions like depths of cut, work speed, wheel speed and others influence the surface roughness and hardening (Ramesh et al. 2004 and Gopal and Rao, 2003). Combinations of these input parameters are to investigate the relation to the surface roughness, temperature generates, material removal rate and G-ratio of the grinding wheel.

2.2 TYPE OF GRINDING

Grinding is most commonly used as a finishing process to achieve material removal and desired surface finish with acceptable surface integrity, dimensional tolerance and form tolerance. The tribological process, two dissimilar material surface contacts and sliding each other produce wear and abrasion on the surface, and the material is rapidly remove from the ground surface. There are many types of grinding such as belt grinder, bench grinder, cylindrical grinder, surface grinder and other. However, this research interested in the surface grinding machines because it was large used in industries.

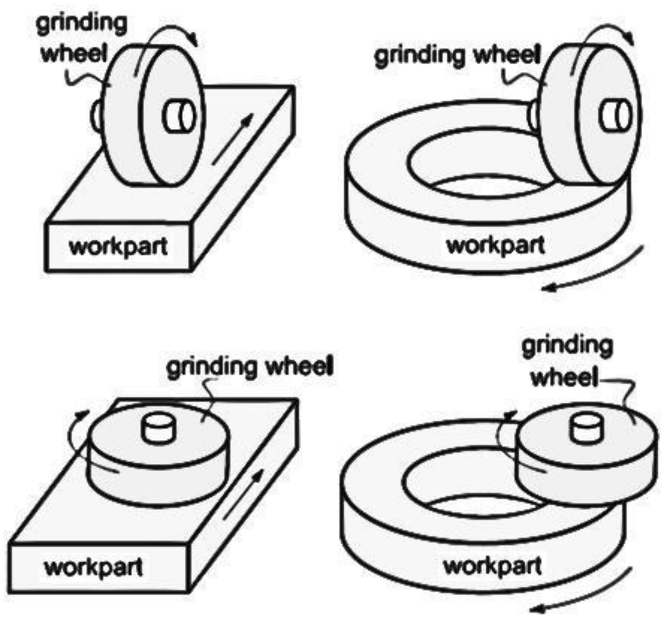

Figure 2.1: Type of grinding

Surface grinding is the most common operation for grinding flat surface and is likely to produce high tolerances, low surface roughness and planar surfaces. In surface grinding, shallow depth of cut was achieved with fast feed rates and the depth of cut can range from 0.01 to 0.05mm while the feed rate is approximately 3m/s (Cameron et al., 2010). Figure 2.1 shows of surface grinding according to the workpiece shape and grinding wheel orientation. Surface grinders come up with lots of facilities. Precision surface grinders have absolutely vibration-free and noise-free operations. Some grinders have to provision for coolant applicants. In certain grinders, there are provisioned for gathering the dust particles, which is generated during the precision process.

2.3 MACHINING PARAMETERS

Grinding practice is a large and diverse area of manufacturing and tool making. It can produce fine surfaces and very accurate dimensions and available for either hard or brittle materials. Previous study stated that grinding conditioned like depths of cut, work speed, wheel speed, etc., influence the surface roughness and hardening. Several parameters involve in grinding machining process such as wheel speed, workpiece speed, depth of cut, type of grinding wheel, wheel grit, coolant flow, coolant concentration, type of coolant and other. However, in this research only interested in depth of cut, type of grinding wheel, type of coolant and finally yet importantly is table speed as their factor to overlook the response.

Depth of Cut: Surface grinding is the most common operation for grinding flat surface and is likely to produce high tolerances, low surface roughness and planar surfaces. In surface grinding, shallow depth of cut is achieved with fast feed rates and the depth of cut can range from 0.01 to 0.05mm (Cameron et al., 2010)

Workpiece Speed: During the surface grinding process, the work moves in two directions. As a flat workpiece is being ground, it moves under the grinding wheel from left to right (longitudinal traverse). This longitudinal speed is called work speed. The work also moves gradually from the front to rear (cross traverse), but this movement occurs at the end of each stroke and does not affect the work speed. The work moves from left to right (cross traverse) as the surface of the cylinder rotates under the grinding wheel (lateral traverse).

Grinding Wheel: There are a lot of grinding discs usually they have been specially coding to represent several data for ones grinding wheel. Cubic boron nitride grains have very high thermal conductivity, which can enhance heat conduction away from the grinding zone to the wheel (Upadhyaya and Malkin, 2004), and therefore, can prevent the thermal damage to the workpiece. Different grinding wheel manufacturers to slightly different methods for defining the specification of their own make of a wheel. They all generally follow the same type of format using a code made up of letters and numbers relating to different features within the wheel. Either this code is marked along the side of the grinding wheel, on the wheel blotter or if the wheels are too small, on an identification card which was sent with the grinding wheel.

Coolant: The cutting fluids used in grinding operations are the same as those used in other machine tool operations. Synthetic coolants are the best, but you also may use a mixture of soluble oil and water. As in most machining operations, the coolant helps to maintain a uniform temperature between the tool and the work to prevent extreme localized heating. Excessive heat will damage the edges of cutters, cause warpage, and may cause inaccurate measurements. In other machine tool operations, the chips fall aside and present no great problem. This embedding cause unsatisfactory grinding and need to dress the wheel frequently. A sufficient volume of cutting fluid helped prevent the loading. The fluid also helps to reduce friction between the wheel and the work and to produce a good finish. According to Verma et al. (2008), MoS_2 in its nanoparticulate form has exceptional tribological properties, which can reduce friction under extreme pressure conditions. Wu et al. (2006) examined the tribological properties of lubricating oils with CuO, TiO_2, and diamond nanoparticles additives. The experimental results show that nanoparticles, especially CuO, added to standard oils exhibit good friction-reduction and anti-wear properties.

Surface Roughness: Surface roughness is variable used for describe the quality of ground surface as well as competitiveness of overall grinding system as it determines the quality of the workpiece characteristic such as the minimum tolerance, the lubricant effectiveness, and the component life (Hecker and Liang, 2003). When measurements of surface roughness are made, techniques based on statistics can be used to remove the effects of the reference surface (Wyant, 1985). The arithmetic average height parameter (R_a), also known as the center line average (CLA), is mostly used as an index to determine the surface finish in the machining process. It defines as Eq. (2.1):

$$R_a = \frac{1}{l}\int_0^l [y\ (x)]dx \tag{2.1}$$

The roughness average, R_a is the most used international parameter of surface roughness. Surface roughness is the measure of the finer surface irregularities in the surface texture. It was quantified by the vertical deviations of a real surface from its ideal form. The surface is rough when the deviations are large while the surface is smooth when deviations are small and (Zhong and Venkatesh, 2008) a good-quality surface for the most industrial is with arithmetic mean roughness, R_a below 0.8μm. Prediction and identification of surface roughness has been the subject of many researchers in the manufacturing field. From the literature, the modeling and prediction problems of surface roughness of a work-piece by mathematical modeling have received increasing attention.

Temperature: Grinding is tribological process where two dissimilar material surface contacts and sliding each other produce wear and abrasion of the surface, and the material is rapidly removed from the ground surface. Through this process, almost all energy converts to heat and make the temperature rising up. The heat becomes concentrated in grinding zone so that the workpiece will be heated at high temperature and possibility the workpiece damage by the thermal is increased. Temperature depends on a range of factors, including the type of coolant, method of coolant supply, type of grinding wheel and the speed and depth of cut. The heat generated in the process and plastic deformation in the surface layer of the part will produce a considerable amount of residual mechanical stress. (Guo et al., 2009). Temperature problems in scratching and grinding were, first studied in metal parts fabrication, in which a possible thermal burning may damage the tools and workpieces. The turning and grinding metals requires high input of energy per unit volume of material removal (Kohli et al., 1995), some of that heat is taken away by coolant, chips, workpiece and tool. The fraction of heat entering the workpiece is directly related to the temperature rise of the workpiece.

G-Ratio: Tool wear is normal in the machining process. However, they are many researches done to minimize this tool wear. G-ratio is the parameter that interested to analyze the tool wear. The grinding wheel wear occurs due to the friction between the abrasive grains and the workpiece. High fluid lubricating capacity reduces the wear on the grinding wheel by decreasing grain-workpiece friction, allowing the abrasive grains to remain bound to the binder for longer periods and leading to lower wear of the tool (Silva et al.,2005). G-ratio is accepted a parameter of wheel wear in the grinding ratio. It defines as Eq. (2.2):

$$G = \frac{volumeofmaterialremoved}{volumeofwheelwear} \tag{2.2}$$

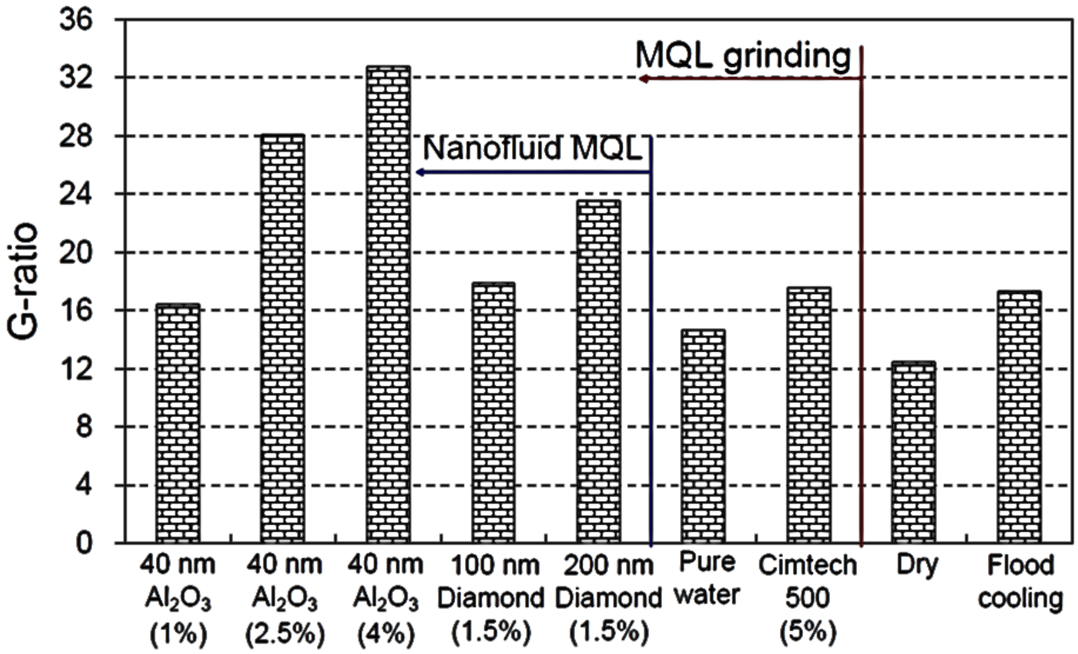

Figure 2.2: G-ratio of various nanofluid coolant and different techniques

Figure 2.2 shows the experimental results of the G - ratio, which is defined as the volume of material removed per unit volume of grinding wheel wear, could be improve with high concentration nanofluids. A high G-ratio indicates low wheel wear rate (Shen et al., 2008). In early research; it was found that a thin slurry layer of silicon carbide on the wheel surface could protect the bonding material from thermal and/or mechanical degradation or damage, thereby causing a high G-ratio (Komanduri and Reed, 1980).

2.4 NANO FLUIDS

Nanofluids generally classified into two categories, which is metallic nanofluids and non-metallic nanofluids (Eastman et al., 2004). Metallic nanofluids often refer to those containing metallic nanoparticles such as copper (Cu), ferrum (Fe), gold (Au) and silver (Ag), while nanofluids containing non-metallic nanoparticles such as aluminum oxide (Al2O3), copper oxide (CuO) and silicon carbide (SiC) are often considered as nonmetallic nanofluids. The measured thermal conductivity of the nanofluids containing 10, 30, and 60 nm-sized ZnO particles are 0.637, 0.627, and 0.618 $W \cdot m^{-1} \cdot K^{-1}$ at 20 °C, respectively, at a volume fraction of 1 % while that of pure water is 0.607 $W \cdot m^{-1} \cdot K^{-1}$. Note that the thermal conductivity of ZnO is 29 $W \cdot m^{-1} \cdot K^{-1}$ at 46 °C. The enhancement ratio relative to pure water is therefore 1.8~4.9 %. The enhancement ratio increases with the volume fraction and reaches 7.3~14.2 % at 3 % volume fraction. The measured thermal conductivity of the nanofluid is inversely proportional to the mean size of the suspended particles at a fixed volume fraction, suggesting that the laser fragmentation process can increase the thermal conductivity. Variation of the thermal conductivity ratio of ZnO nanofluid with temperature is shown in Figure 2.3. As observed earlier, the thermal conductivity ratio increases with an increase in temperature as well as particle volumetric concentration (Vajjha and. Das, 2009).

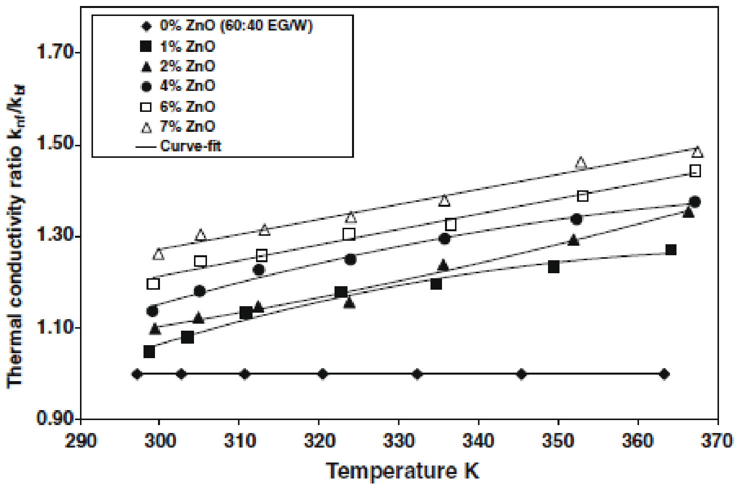

Figure 2.3: Variation of the thermal conductivity ratio of ZnO nanofluid with temperature

There has not been a systematic experimental investigation of size-dependent conductivity reported (Jang and Choi, 2004). However, Wang et al. (1999) compared their experimental data with those of other investigators, and concluded that it is possible that the thermal conductivity of nanoparticle fluid mixtures increases with the decreasing particle size. How the particle size affects the thermal conductivity of nanofluids will be studied in this research. Figure 2.4 shows the nanoparticle size of zinc oxide (Shen et al., 2008).

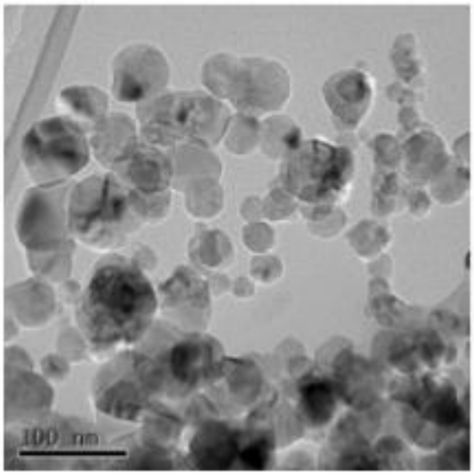

Figure 2.4: Nanoparticle size of zinc oxide

2.4.1 Cooling Applications

Nanofluid can enhance thermal conductivity that affects the heat transfer rate. Thermal conductivity also goes up with fraction of nano-particle. However, there is a little information on nanofluid as a coolant since this is new thing and the result from the research that had done come with lack of consistency result regarding thermal properties (Murshed et al., 2008, Wong and Kurma, 2008). Nanofluid had been using for cooling application in industries such as in nuclear reactor, transportation, automotive application, electronic and lubrication (Yu et al., 2008). Phase change nanoparticle in nanofluid simultaneously enhances the effective thermal conductivity and specific heat of the fluids. This leads to similar studies allow industrial cooling applications to continue without thorough understanding of all the heat transfer mechanisms in nanofluids (Han et al., 2008). High thermal conductivity in nanofluid that resulted from add the nanopartilce really benefit the conventional fluid like engine oils, automatic transmission fluids, coolants, lubricants, and other synthetic high temperature heat transfer fluids usually found in conventional transportation such as car, truck radiators, engines, heating, ventilation and air-conditioning (HVAC) which known inherently have poor thermal properties (Yu et al., 2008; Chopkar et al., 2006). The application of nanofluid also contributed to a reduction of friction and wear, reducing parasitic losses, operation of components such as pumps and compressors, and subsequently leading to more than 6% fuel savings. When using high-thermal conductive nanofluids in radiators, it can lead to a reduction in the frontal area of the radiator by up to 10%. This reduction in aerodynamic drag can lead to a fuel savings of up to 5%. Table 2.1 is listed the thermal conductivity of various nanofluids (Singh et al.,2006).

Table 2.1: Thermal conductivity for various nanofluids.

Material	Thermal conductivity (w/m-K) @ 300K
Metallic solid	
Copper	401
Aluminum	237
Titanium	22
Nonmetallic solids	
Diamond	2300
Silicon	148
Aluminum Oxide	36
Conventional heat transfer fluid	
Water	0.613
Ethylene Glycol	0.252
Engine Oil	0.145

2.4.2 Lubrication Applications

To improve the tribological properties of lubricating oils by dispersing nanoparticles, especially nanoparticulate solid lubricants, becomes of interest to societies. Research has shown that lubricating oils with nanoparticle additive's exhibit improved load-carrying capacity, anti-wear and friction-reduction properties. (Xu et al., 1996) investigated tribological properties of the two-phase lubricant of paraffin oil and diamond nanoparticles, and the results showed that, under boundary lubricating conditions; this kind of two-phase lubricant possesses excellent load-carrying capacity, anti-wear and friction-reduction properties. According to (Verma et al. 2007), MoS2 in